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European Community Can Reduce CO_2 Emissions by Sixty Percent: A Feasibility Study

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Carbon dioxide (CO_2) emissions in the European Community (EC) can be reduced by roughly 60 percent. A great many measures need to be taken to reach this reduction, with a total annual cost of ECU 55 milliard. Fossil fuel use is the main cause of CO_2 emissions into the atmosphere; CO_2 emissions are to a large extent responsible for the greenhouse effect. Energy saving (conservation) and nuclear energy appear to be the least expensive methods of CO_2 abatement, directly followed by renewables. More expensive alternatives include the separation of CO_2 at the source (e.g., power plants), followed by storage in depleted gas fields, aquifers, or in the ocean. Biological options, such as reforestation and energy farming, are the most expensive abatement methods; however, they do have secondary advantages, such as avoided fallow premiums and avoided export premiums on cereals. Application of all measures together can lead to the 60 percent reduction goal.

On behalf of the European Community (Directorate General XI), an analysis was made of possible solutions for confining and abating CO_2 from fossil fuel burning. The study was performed by a team of specialists from various disciplines, within both TNO Institute of Environmental and Energy Technology and The Netherlands Institute for Oceanic Sciences (NIOZ).

The essence of the CO_2 problem is not the fact that CO_2 is being emitted. Actually, there is an intensive exchange of CO_2 between the atmosphere and biomass on earth, as well as between the atmosphere and oceans. In fact, the 5.5 Gtons C/year emitted from fossil sources (Figure 1) are small compared to the estimated annual exchange of 50 Gtons C/year between the atmosphere and biomass, and the 100 Gtons C/year between the atmosphere and oceans.

It is, however, essential that the 5.5 Gt C/year from geological formations is *added* to the atmosphere, as the CO_2 concentration in the atmosphere is thus increased (Figure 2); this concentration is now higher than it has been in millions of years. The resulting rise in temperature is still only marginally demonstrable (Figure 3), but its presence is hardly doubted.

This study focuses mainly on the CO_2 situation in the EC. Statistics show that approximately 13 percent of global CO_2 emissions originate from the EC (0.745 Gt C/yr). About 25 percent of these 0.745 Gt emanate from large point sources (mainly large power plants); the remaining CO_2 emissions (traffic and transport, industry, built-up areas) are for the most part diffuse, i.e., originate from small (point) sources.

Basic Solutions

Carbon dioxide emissions can be reduced by changing the fuel mix and removing CO_2 from the combustion processes of fossil fuels. After removal, the CO_2 must be stored in either geological formations or the ocean. Another means of abatement is to promote the development of useful applications of CO_2.

Other solutions include energy farming, reforestation, afforestation, and the discouragement of deforestation. The last solution is specifically important for tropical areas. Finally, important basic possibilities in this context include energy saving, use of sustainable energy sources, and nuclear energy.

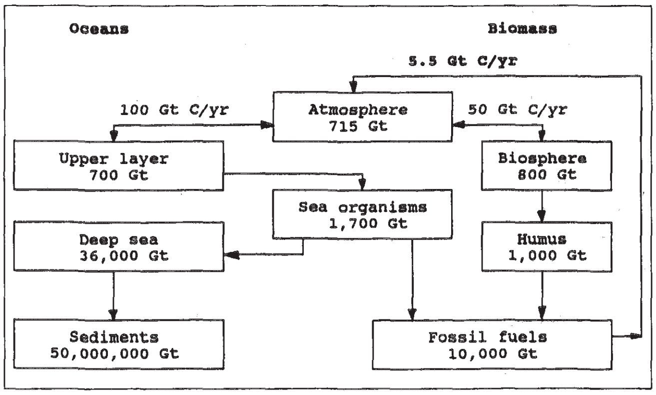

Figure 1. Simplified chart of the carbon cycle.

Change in Fuel Mix

Using fuel with more hydrogen and less carbon causes a decrease in CO_2 emission per PJ. The extremes in this respect are coal ($CH_{0,37}$ to $CH_{0,67}$) and natural gas (CH_4); oil and LPG are found in between the two extremes. Table I reflects the 1988 energy consumption in the EC.

Theoretically, switching from 100 percent coal to 100 percent natural gas would cut CO_2 emissions by 42 percent. Changing from the fuel mix mentioned in Table I to natural gas would result

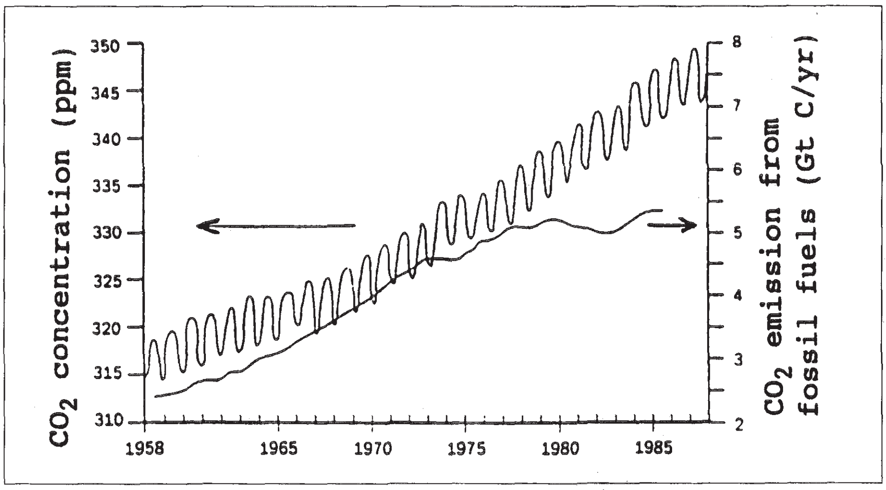

Figure 2. CO_2 concentration in the atmosphere, measured at Mauna Loa, Hawaii, and CO_2 emission from fossil sources.[1]

in a theoretical 30 percent CO_2 emission reduction. However, since there is a methane loss of approximately 2 percent due to leakage and a loss of noncombusted natural gas emissions (which percentage, for that matter, is under discussion), the net effect will be much smaller, since the greenhouse effect of CH_4, per molecule, is 20 to 27 times that of CO_2. Thus, less than 10 percent would remain of the previously mentioned theoretical 42 percent reduction. The effect of a change in fuel mix must therefore be considered limited.

Useful Applications of CO_2

The total amount of CO_2 currently used worldwide is estimated to be several million tons per year, which is in the range of 0.1 percent of the CO_2 emission from fossil fuels. Figure 4 gives a representation of the principal applications.

Due to the greenhouse effect, we are now seeking an extension of applications. With the exception of energy farming, the previously mentioned possibilities are probably limited. One limiting condition in this respect is that CO_2 should not end up back in the atmosphere quickly. Also, processes replacing fossil carbon consumption are relevant in this context. The latter is the case with energy farming, where the CO_2 from the atmosphere is used for biomass growth (plants, trees, algae). Energy is then recovered, again causing CO_2 to be emitted. Thus a carbon subcycle is created, preventing an equivalent quantity of fossil carbon from being added to the atmosphere. Energy recovery from biomass can take place through either ethanol production, gasification, pyrolysis, digestion and combustion, or by using vegetable oil in engines (Elsbett engine). All these options are rather expensive.

Separating CO_2 from Flue Gases Followed by Storage

In order to be able to store CO_2 in geological formations or in the ocean, CO_2 must become available in reasonably high concentrations (i.e., > 90 percent), as otherwise the costs would become too high. There are two basic possibilities: separation afterwards from the flue gas, or firing with oxygen instead of air. Several methods are available for separation afterwards, such as absorption, adsorption, condensation, chemical or biochemical reactions, or membrane techniques. Currently, the prevailing opinion is that, financially, separation using membranes in combination with absorption in MEA (monoethanolamine) works out most favorably (or least unfavorably).

The CO_2 concentration of flue gases from conventional combustion processes is low, 9 to 15 percent, however. A more efficient route is to make use of a coal gasification process with energy transfer through a steam and gas turbine (a coal gasification steam and gas turbine cycle). In this route, the coal gas produced is converted mainly to CO_2 and H_2, via a shift reaction. The CO_2 concentration is thus increased to about 40 percent; hence it can be separated more efficiently. However, combustion with oxygen also appears to be economically attractive.[4] The flue gas then consists almost completely of CO_2. The oxygen is recovered from the air in advance, for example cryogenically. The consequence, however, is that various parts of the installation must be designed anew.

In all cases, CO_2 separation uses quite a lot of energy, around 20 percent of the generated capacity. One should realize, however, that these problems have only been considered for a very short period. It is certain that in the years to come, fundamental new developments can be expected in this field which will lead, among other things, to a more energy-efficient CO_2 separation.

Storage of CO_2 in Depleted Gas Fields

Once the CO_2 has been separated, it can be transported to depleted gas fields in order to be injected there. In The Netherlands, an equivalent of 2.6 Gt C of space is available; for the European Community (EC) this amounts to 7.6 Gt C (including The Netherlands).[5] This means that this storage possibility can only be utilized for some decades. An advantage of gas fields is that their suitability for gas storage has been actually proven. This implies, among other things, the presence of a caprock which is sufficiently gas tight (aquitard). Further, in certain cases the production of natural gas can be promoted by injecting CO_2. In some cases, this injection is already taking place.

Storage in Aquifers

The presence of oil or natural gas in geological formations is an exception; the presence of water, however, is a rule. The volume of aquifers in the EC is thus several times larger than that of oil fields and gas fields. On the other hand, there is much more uncertainty with respect to their suitability for gas storage.

Knowledge about aquifers in the EC is more restricted than knowledge about oil fields and gas fields, since the presence of

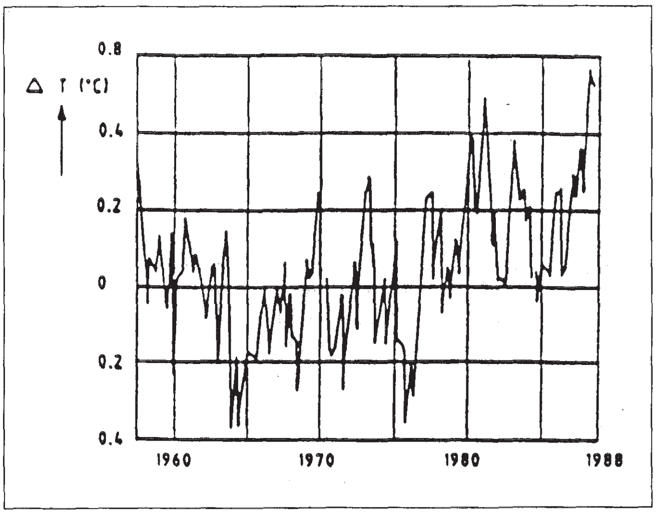

Figure 3. Quarterly changes in average world temperature at 2 m height.[2]

aquifers hardly implies any commercial interest. Aquifers have been inventoried within the framework of the EC geothermal research.[6] The information, however, is still very incomplete, specifically for young EC countries. Furthermore, the criteria for geothermal recovery are completely different from those for CO_2 storage. A first rough estimation is that aquifers are found in the EC for an equivalent of about 550 Gt C and that, for instance, 5 to 20 percent of those aquifers may be suitable for CO_2 storage.

A basic question to be posed in this respect is what quantitative demands are put to storage. As a caprock is less domed and an aquitard less dense, there is less question of controlled storage; one should rather speak of uncontrolled disposal. This will certainly be a topic for extensive discussions. For the time being, the basic premise of this study is that aquifers can be used for CO_2 storage for several hundreds of years.

Storage in Salt Caverns

Salt caverns cannot qualify for storage of CO_2 from fossil fuels, as their total volume in the EC is much too small.

Storage in Oceans

Comparison of the quantity of carbon emitted from fossil fuels and the increase in atmospheric carbon concentration reveals that the oceans absorb about 50 percent of the CO_2. This figure is rather uncertain, because the quantity of biomass on the continent which also affects the atmospheric CO_2 concentration is also subject to continual change. Think in this regard of the advancing deforestation in tropical areas.

Carbon in the oceans largely occurs as the bicarbonate ion HCO_3^-, and further as sea organisms and sediments (Figure 1). It is very difficult to affect the behavior of the oceans in order to accomplish an increased rate in carbon absorption. The addition of nutrients, such as nitrogen (N) and phosphorus (P), in order to promote the growth of organisms, is considered inefficient.[7] The impression is that CO_2 injected into the ocean is ultimately re-emitted. The deeper the injection, the longer the period between injection and emission.

The investigation now aims at the mixing behavior of currents. A current near Gibraltar that moves to a depth of some 1200 m in the Atlantic Ocean is relevant for the EC. If CO_2 were injected into that current, it would take an estimated 50 to 200 years before 50 percent of it will re-enter the atmosphere.

Storage of CO_2 in Biomass

Storage of CO_2 in biomass is the most natural way of CO_2 emission reduction. This storage can take place either temporarily in the form of energy farming, or permanently by increasing the biomass area. In this respect, it is important that additional CO_2 is bound only through *increasing* that area; basically, a mature forest, for example, does not absorb any more CO_2.

Since CO_2 is quickly and equally dissipated in the atmosphere, the problematic situation of deforestation in tropical areas is also of importance for the EC. The estimated deforestation[8] of 10 to 25 x 10^6 ha/yr corresponds to 2.3 to 5.6 Gt C/yr. The maximum estimate, therefore, is the same as the global carbon emission through fossil fuels! An EC policy that aims at reversing this deforestation and promoting new afforestation is therefore extremely important.

Another important issue is that there is 25 to 30 x 10^6 ha of redundant farmland in the EC, which requires the payment of fallow premiums. Further, there is surplus grain in the EC, on the basis of which export premiums are granted. By using these areas for energy farming or afforestation, these premiums would no longer have to be paid.

Table I. Energy consumption in the EC (1988).[3]

Energy source	Oil equivalents (Mtroe)	Net caloric value (EJ)	%
Hard coal	194	8.1	18
Lignite/peat	33	1.4	3
Crude oil	488	20.4	45
Natural gas	193	8.0	18
Nuclear energy	147	6.2	14
Primary energy	18	0.8	2
	1,073	44.9	100

Options for Prevention

Within the framework of this study, preventive options, in particular energy saving, sustainable energy sources (such as sun, wind and hydropower), and nuclear energy, have also been considered. These options have not been thoroughly analyzed; the only purpose was to compare them with the options mentioned, insofar as their potentials and costs were concerned.

Presumably, an annual energy saving of 2 percent, cumulatively over a 10-year period, is feasible in the EC (analogous to a similar policy decision in The Netherlands).

It has further been assumed that in the year 2010, 5 percent of energy will come from sustainable energy sources (EC policy decision). Finally, it has been assumed that 20 percent of the current power plants would switch from fossil fuels to nuclear energy.

Financial Consequences

In order to be able to compare the figures better, a distinction is being made between gross and net costs. This is particularly the case for energy saving, sustainable energy sources, nuclear energy, and energy farming, where the profits of saved fossil energy production and use are subtracted from the gross costs in order to obtain the net costs.

It turns out that energy saving and nuclear energy are relatively cheap. Sustainable energy sources are also attractive. The cost estimates for energy saving and sustainable energy have been derived from the "Dutch Memorandum on Energy Saving,"[11] extrapolated for the EC. The costs as calculated in a Dutch study on Sustainable Energy[9] have been chosen as a starting point for nuclear energy. These costs have been raised by 25 percent in order to cover the dismantling of nuclear power plants and the processing of radioactive waste. The three storage possibilities (gas fields, aquifers, oceans) do not differ much. This is mainly due to the fact that the CO_2 separation costs comprise about 90 percent of the total costs. The quantity of CO_2 that could be

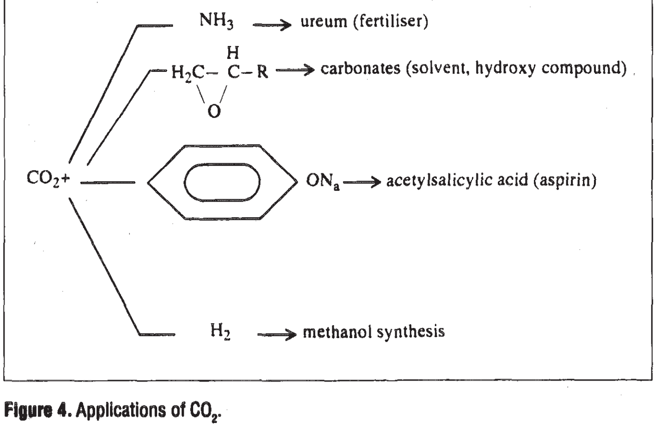

Figure 4. Applications of CO_2.

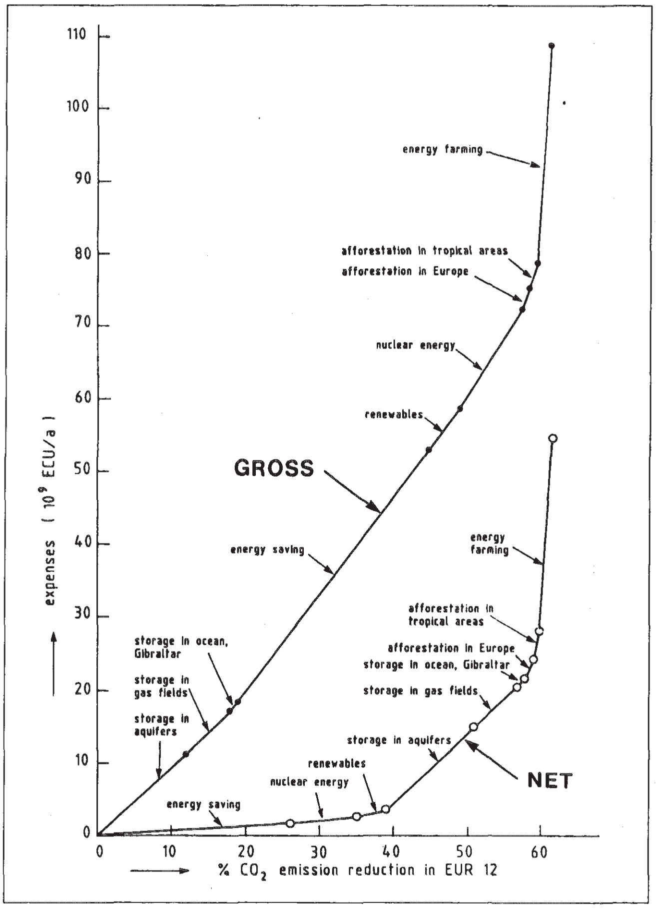

Figure 5. Costs and effectiveness of CO_2 abatement in the EC.

injected at Gibraltar is small, as there are only a few fossil-fueled power plants near Gibraltar.

Reforestation in tropical areas appears to be relatively expensive, as the soil there is usually very poor in minerals, which is a requirement for the binding of carbon. The costs of conventional forestry was the starting point for reforestation in the EC.

With energy farming, finally, total production costs (including the production of ethanol) have been chosen as a starting point, on the basis of data from the United States. Figure 5 gives a quantitative summary of the different options.

Needless to say, this is a rough cost comparison. In fact, any option is a composition of a great many suboptions, varying from "cheap" to "expensive". There are also important differences in cost estimates of both options and suboptions. In addition, many of these options imply positive and negative side effects that could not be taken into account here. For instance, sustainable energy sources and energy savings imply a reduction in acidification and a saving of natural resources. Nuclear energy does not yet have public acceptance and involves certain risks; forests can promote tourism, etc.

Figure 5 shows the amount of CO_2 that can be technologically avoided by the respective options, as well as their financial implications. Both for "Gross" and "Net" costs, the options have been placed in a sequence of increased costs per unit of CO_2 avoided. Gross implies the total costs for CO_2 avoidance; in the Net costs, the savings due to avoided use of fossil energy, are taken into account.

If only CO_2 emission reduction is considered however, a total reduction of roughly 60 percent is feasible by taking all measures together, at gross costs of approximately ECU 110 milliard per year, or net costs of ECU 55 milliard per year.

A 60 percent CO_2 emission reduction, however, means only a 30 percent reduction in greenhouse gases. Therefore, it is logical that the reduction in emissions of other greenhouse gases, in particular CH_4 (methane), N_2O (laughing gas), and CFCs (halogenated hydrocarbons) is considered simultaneously in order to reach a maximum reduction in CO_2 emission *equivalents* at minimum costs.

Future Options

A more drastic CO_2 emission reduction is possible only on the basis of the "breach-of-trend" concept, involving setting fundamentally new norms and goals in society. Examples of such breaches of trend are: (1) an increased application of wind energy with a factor of 100 or more; (2) a general public acceptance of inherently safe nuclear energy, including breeding reactors; and (3) an integrated systematic approach to the problems involved in global population growth.

In practice, the optimum policy is probably a mix of the options presented in this study with the breaches of trends.

Acknowledgment

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References

1. J. Legget, Ed. *Global Warming: The Greenpeace Report*, Oxford University Press, 1990.
2. Schutz der Erdatmosphäre, "Zur Sache: Themen parlementarischer Beratung," Deutscher Bundestag, Bonn, Germany, 1988.
3. *Eurostat: Energy Statistical Yearbook 1988*, Statistical Office of the European Communities, ISBN 92-826-1200-7, Brussels/Luxemburg, 1990.
4. C.A. Hendriks, K. Blok, W.C. Turkenburg, "The Recovery of Carbon Dioxide from Power Plants," in *Climate and Energy: The Feasibility of Controlling CO_2 Emissions*, P.A. Okken, R.J. Swart, S. Zwerver, Ed., ISBN 0-7923-0520-5, Kluwer, Dordrecht, The Netherlands, 1989.
5. K.W. Glennis, J. Brooks, J.R.V. Brooks, "Hydrocarbon Exploration and Geological History of North West Europe," in *Petroleum Geology of North West Europe*, K.W. Glennis, J. Brooks, Ed., Graham & Trotman, London, 1987.
6. R. Haenel, E. Staroste, Ed., "Atlas of Geothermal Resources in the European Community, Austria and Switzerland," Publication No. EUR 11026 of the Commission of the European Community, Brussels/ Luxemburg, 1988.
7. H.J.W. de Baar, "Options for Enhancing the Storage of Carbon Dioxide in the Oceans; a Review," First International Conference on Carbon Dioxide Removal, Amsterdam, The Netherlands, 1992.
8. D.A. Lashof, D.A. Tirpak, "Options for Stabilizing Global Climate," U.S. Environmental Protection Agency, 1989.
9. N.R.A. Krekel et al. "Duurzame energie, toekomstverkenning Krekel," Van der Woerd, and Wouterse, Rotterdam, The Netherlands, 1987.
10. G.J.M. Mohren, C.G.M. Klein Goldewijk, "CO_2-vastlegging in bos; eindrapport deelproject I: CO_2-vastlegging en bosbouw in Nederland," De Dorschkamp, Institute for Forestry and Green Management, Wageningen, The Netherlands, 1990. (AUTHOR: this reference is not cited in text)
11. Nota Energiebesparing, "Second Chamber of the States General," 1989-1990, 21570, No. 1-2.

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